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USSR Report

MATERIALS SCIENCE AND METALLURGY

(FOUO 4/82)

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AVIATION MATERIALS

UDC: 669.017.018.5 (075.8)

AVIATION INSTRUMENT ENGINEERING AND STRUCTURAL MATERIALS

Moscow MATERIALY DLYA AVIATSIONNOGO PRIBOROSTROYENIYA I KONSTRUKTSIY in Russian (signed to press 19 Nov 81) pp 2-4, 397-400

[Annotation, foreword and table of contents from book "Materials for Aviation Instrument Engineering and Structures", edited by Academician A. F. Belov, Izdatel'stvo "Metallurgiya", 3300 copies, 400 pages]

[Text] This textbook examines conductor, semiconductor, dielectric, magnetic and structural materials employed in aviation instrument engineering and structures. Their electrical, magnetic and mechanical properties are described. Principal attention is devoted to an analysis of the relationship between the properties of materials, their composition and structure. Practical application of specific materials in designing aircraft equipment is shown.

This textbook is intended for students enrolled at aviation higher educational institutions. It may also be of use to engineers and technicians in the metallurgical and aircraft industry.

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FOREWORD

This country's aviation higher educational institutions offer lecture courses on the properties of structural and electrical engineering materials employed in aviation instrument engineering. There are no standard textbooks and manuals on this subject, however; at the same time considerable Soviet and foreign information on specific materials is contained in numerous periodicals and monographs and requires certain systematization.

Thus there arose the need to produce a textbook combining within the framework of established curricula not only basic information on theory of modern specialized materials for aviation instrument engineering, but also on their practical application.

In writing this book the authors were guided by the current course curriculum "Structural and Electrical Engineering Materials" for Aviation Higher Educational Institutions. This book consists of two parts. The first part deals with materials with special physical and physicomechanical properties. It examines conductor and semiconductor materials, materials with special magnetic properties, and materials with special physicomechanical properties.

The second part of this textbook contains a general description of nonmetallic materials and examines the physical, mechanical, and chemical properties of thermoplastics, synthetic resins, raw and cured rubber, graphite, ceramics, glass and sitalls, as well as filamentary and film-forming materials, plastics and polymer-base composite materials.

Considerable attention is devoted to study of the most difficult and new areas of materials science, which are lacking or are inadequately treated in existing textbooks and manuals. The following sections, for example, are contained for the first time in this textbook: "Materials With Special Electrical and Mechanical Properties Operating in Conditions of Corrosion Effect"; "Physico-chemical Principles of Heat Treatment of Semiconductors"; etc. Considerable attention is devoted to fundamentally important questions connected with analysis of the relationshp between the properties of materials, their composition and structure, for the purpose of determining possibilities of application of specific materials in aircraft equipment. In conformity with the curriculum, the authors also sought to reflect in this textbook important materials connected with the future area of specialization of engineers.

The literature listed at the end of the book is recommended for a more thorough study of a number of subjects. Compositions of alloys in this book are stated as percentages by mass.

Subsections 1-5 of Chapter 1 and Chapter 6, Part I, were written by T. S. Morozova; Subsection 6 of Chapter 1, Part I -- Ye. V. Ryabchenko; Subsection 7 of Chapter 1 and Chapter 9, Part I -- V. S. Terent'yeva; Subsection 8 of Chapter 1, Part I -- A. A. Klypin; chapters 2 and 10, Part I -- Yu. P. Frolov; the Foreword, chapters 3-5 of Part I -- A. Ya. Potemkin; Chapter 7 of Part I -- V. V. Nikolenko; Chapter 8 of Part I -- M. G. Karpman; Chapter 11 of Part I -- G. P. Benediktova and A. A. Klypin; Chapter 12 of Part I -- A. S. Viskov; Chapter 13 of Part I -- G. P. Fetisov; the introductory part, Subsection 1 of Chapter 1, chapters 3, 5, 7, 8-14, and 17 of Part II -- Yu. I. Sheydeman; subsections 2-5 of Chapter 1, chapters 2, 4, 6, 15 and 16 of Part II -- G. Ye. Vishnevskiy.

This textbook was readied for publication by Doctor of Chemical Sciences Professor A. Ya. Potemkin (Part I) and Candidate of Technical Sciences Docent I. Yu. Sheydeman (Part II).

The authors would like to express their deep gratitude to the reviewers for valuable comments made during perusal of the manuscript: to Doctor of Technical Sciences Professor P. T. Kolomytsev and the faculty members of the Department of Materials Science of Electronic Equipment at the Moscow Institute of Electronic Machine Building, Doctor of Technical Sciences Professor A. A. Shmykov, chairman. The authors are also very grateful to the faculty and staff members of the Department of Aviation Materials Science at the Moscow Aviation Institute for their considerable assistance in readying the manuscript for publication.

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ECONOMY OF METALS

IMPROVING STRUCTURE OF METALS INPUT IN INDUSTRY

Moscow VOPROSY EKONOMIKI in Russian No 4, Apr 82 pp 75-82

[Article by N. Ivantsova: "Metals Intensiveness of Production and Reserve Potential for Achieving Savings in Metal"]

[Text] The CPSU Central Committee and USSR Council of Ministers decree entitled "On Intensifying Efforts for Economy and Efficient Utilization of Raw Materials, Fuel-Energy and Other Material Resources" specifies a group of concrete measures to improve the system of planning and incentive applying to utilization of material resources. The objective is to achieve savings in resources both in the production process proper and in consumption of the finished product.

Machine building, metalworking and construction are the principal consumers of finished metal products. The growth rate of these industries, change in their structure, and the level of metals input [metalloyemkost' -- also translated as "metals requirements" and "metals intensiveness"] in production exert direct influence on the volume of metal consumption and metals input of societal product. Machine building and metalworking consume the largest volumes of metal. In the structure of material outlays of machine building and metalworking, for example, metals comprise approximately 30 percent taking into account internal turnover within the machine building industry, and 50 percent excluding it, that is, they comprise the bulk of the material outlays in this branch.

The level of metals input in production is still comparatively high, which leads to considerable metal waste in the metal-consuming branches. At the 26th CPSU Congress L. I. Brezhnev noted that reduction of losses and waste in metalworking by only one half would be equivalent to a 10 percent increase in output of finished ferrous metals rolled stock. Metal waste in consuming branches is growing and presently exceeds 19 million tons per year (including 9 million tons into chips). The rolled metals utilization factor in machine building has remained unchanged in the last 10 years -- 0.72. The decree on economizing in material resources notes the necessity of improving the structure of the economy, its branches and sectors in the direction of all-out reduction in the energy and materials requirements of production.

The specific metals input of production varies from one branch of machine building and metalworking to another, and therefore changes in the branch structure of this complex exert differing effect on the production metals input of machine building, industry, and societal product as a whole. Heavy, power, transport, tractor and agricultural machine building are the most metals-intensive within machine building. Their percentage share of branch gross output is high (almost 30 percent) and exerts an influence on growth of the production metals input of all machine building. In the future the production volume growth rate of these branches will slow somewhat and the percentage share of their output in machine building will decline, which will cause a decrease in the production metals input of machine building as a whole. The level of production metals input of the road, construction and chemical machine building and automotive industry is close to the level of production metals input of machine building as a whole. The percentage share of this group of branches will increase and cause a certain rise in the production metals input of machine building as a whole.

Machine tool building, machine building for light industry and the food processing industry, the electrical equipment industry, and especially instrument engineering are characterized by a lower metals input. The level of production metals input in instrument engineering is 1/17th that of heavy, transport, and power machine building. Intensive development of the above-listed branches with a lower metals input will promote a decrease throughout machine building, although metal consumption volumes will rise.

Studies of the internal structure of individual machine building subbranches attest to considerable reserve potential for reducing the metals input of machine building production on the basis of improving the structure of its subbranches and design of the products manufactured. The structure of production of tractors, machine tools and certain other machinery and equipment remains fairly metals-intensive. For example, caterpillar tractors comprise a substantial share in the structure of tractor manufacture (40 percent). Standard metal consumption per crawler tractor is 80 percent more than for a wheeled tractor. In the future we should improve the structure of manufacture of tractors, increasing the manufacture of wheeled and small-horsepower tractors, including orchard-and-garden tractors. This will help reduce the metals input of the tractor industry and machine building as a whole.

The most effective ways to reduce production specific metals input per unit of principal machine parameters are concentration of power in one unit, increased productivity and improved performance characteristics of machinery and equipment. In recent years there has been observed in many types of equipment a gap between the technical capabilities of machinery being manufactured and the level of its actual utilization, that is, improved performance is far from fully utilized. For example, the volume of large and heavy metalworking equipment is considerable within the structure of manufacture of metal-cutting machine tools and press forging equipment. This ratio causes an increase in the production metals input of machine tool building and machine building as a whole, while large machine tools are not always used at full capacity. This leads to inefficient expenditures not only of material but of labor resources as well. It is therefore very important that designers and engineers, when designing machinery and equipment, proceed from the actual conditions of equipment utilization.

Improvement of the type-size structure of machinery and equipment remains a pressing matter. Herein lies significant reserve potential for achieving savings in metal and other productive resources. With unchanged metal resources, using the same production facilities and with comparatively small additional outlays, it is possible substantially to increase output of machine building products. In order to determine this reserve potential one should calculate specific metals input when designing machinery and subsequently during operation not only for specifications and performance characteristics but also for work performed. This indicator is determined by the ratio of all material outlays (production and operation) to the volume of work performed by a machine during its service up to the first major overhaul. Work to optimize the type-size structure of machines should be performed in all branches of machine building. It is noted in the Basic Directions of Economic and Social Development of the USSR in 1981-1985 and the Period up to 1990 that it is essential to increase within optimal limits the unit power output of machinery and equipment with a simultaneous decrease in their physical size, metals input, power consumption, and a decrease in the cost per unit of end useful effect.

Efficient utilization of metal products in consuming branches and elaboration of ways to achieve savings in metals during their processing depend in large measure on metal product manufacturing branches. In spite of certain advances in the area of improving the structure and qualitative characteristics of metal, the requirements of the branches and sectors of the nation's economy in the majority of highly economical types of rolled stock are far from being fully satisfied. Many machines of Soviet manufacture are heavier than counterpart foreign-built units, primarily because of an insufficiently modern structure of the metal: a comparatively high percentage share of castings in the structure of metal production and an insufficient percentage share of rolled plate, and especially sheet, in the structure of rolled metal products.

Factors which determine the level of metals input, reliability and durability of machines, instruments, and structures include the quality and structure of ferrous metals. A decrease in structural metal requirements is promoted by improvement in the structure of metal production -- a decrease in the percentage share of castings and an increase in the share of rolled products, incuding sheet and economical products. In recent years the structure of consumed ferrous metals has been characterized by progressive trends, but the percentage share of castings continues to remain comparatively high (see table).

Consolidated Structure of Metal Consumed in Machine Building (as percentages)

Consuming Branches (1)	Percentage Share of Castings in Metal Production (2)		Percentage Share of Plate and Sheet in Finished Rolled Stock (3)	
	1966	1980	1966	1980
Machine building and metalworking	31.1	27.8	46.9	52.6
of that:				
tractor and agricultural machine building	38.8	31.9	35.5	43.2

Table on preceding page, cont'd

(1)	(2)		(3)	
	1966	1980	1966	1980
heavy machine building	32.9	33.3	46.3	49.7
automotive industry	18.6	18.5	40.3	49.0
machine tool industry	51.5	51.1	30.3	38.0
road, construction machine building	29.9	24.0	54.7	59.2
chemical machine building	35.4	34.7	48.0	61.3

As is evident from the figures in the table, the structure of metal for machine building as a whole changed insignificantly during the 15 years: the percentage share of castings declined by 3.3 percent, while plate and sheet production increased by 5.7 percent. In the largest consuming branches -- machine tool building, the automotive industry, heavy and chemical machine building -- the percentage share of castings remained practically unchanged. And an insignificant decrease in the percentage share of castings is planned by 1985 for practically all machine building branches other than machine tools and construction-road construction machine building.

The relatively high percentage share of castings in the structure of metals consumption is due in a number of instances to a shortage of certain types of rolled steel. This leads to the manufacture of castings out of heavy ingots and the forming of a high metals-input structure of certain branches of machine building. Analysis of the structure of castings consumption has shown that in the future castings production in consumption volumes can be reduced by 5-7 million tons per year by replacing cast parts with rolled metal and reducing the weight of castings by adopting precision casting methods. This will make it possible to reduce production metals input and to obtain substantial savings. For example, replacement of parts made of steel castings with welded structures of steel plates generates savings of approximately 103 rubles per ton in calculated expenditures. Consequently, replacement of 5-7 million tons of castings with parts made of rolled stock will make it possible to obtain annual savings of 500-700 million rubles nationwide.

At the present time a number of organizations in this country have completed work on technical-economic substantiation of the fabrication of welded structures out of rolled stock in place of castings. The institutes of the machine tool and tool industry have designed a number of welded machine bed structures of rolled stock in place of cast iron for lathes and grinding machines, machine tools for finish machining, and press forging machines. Work has been completed on development of lighter-weight structural designs for agricultural machinery employing parts fabricated of rolled stock in place of castings.

Considerable work is being done in the area of reducing the metals requirements of machine structures by VNIImetmash [All-Union Scientific Research and Design Institute of Metallurgical Machine Building], which has designed, jointly with the Electric Welding Institute imeni Ye. O. Paton, an automated line for the manufacture of radiators out of sheet steel (in coils, by stamping and welding) in place of cast iron. The mass (specific metal requirements) of an equivalent square meter of a welded radiator made of sheet steel is 3.4 times less than with cast iron. Manufacture of radiators of rolled sheet will save substantial volumes of metal. VNIImetmash has developed a new method of designing prestressed beds for hydraulic presses, rolling and pipe mills. Building presses with prestressed beds reduces metals consumption 2-7-fold in comparison with presses with conventional columns or with a frame arrangement. Stressed-sheathing bed designs for rolling and pipe mills are approximately half as heavy as unit-cast structures.[1]

Rolled product which is presently in short supply is required for going into production with lightweight structures which have already been designed. In the last five-year plan the production growth rate was the same for rolled stock and castings, which is not a sign of progress. Appropriate reorganization of metals production should be accomplished in the next few years, reinforced by a system of economic incentive, in order to ensure that the rolled metals production growth rate (under the condition of allocation of the requisite quantities for replacing castings) exceeds the production growth rate of steel and iron castings.

Reduction in the weight of machinery and equipment is being held back by the extensive employment of merchant shapes in the consuming branches. Merchant shapes continue to represent a substantial percentage within the structure of finished rolled stock: almost 50 percent in machine building and metalworking, and from 50 to 60 percent in certain branches of machine building.

Change in the production structure of finished rolled products is essential in connection with the accelerated development of branches of industry with high requirements in sheet and plate, which are demanding increasingly larger quantities of these products. Sheet and plate production should grow at a substantially more rapid rate than merchant shapes production in order to satisfy the requirements of those branches with high sheet and plate requirements -- the automotive industry and electrical equipment industry; for the manufacture of pipe for natural gas and oil pipelines, structural tubing, curved structural shapes, and coated, plated, and clad sheet; for employment in construction; replacement of castings and merchant shapes. Employment of sheet and plate, and especially cold-rolled, produces considerable economic effect. Calculated outlays per ton of finished parts (rubles per ton) fabricated of sheet and plate are approximately 20 percent less than with merchant shapes. With an increase in the percentage share of plate and sheet in the rolled products structure to 50 percent (it is approximately 40 percent at the present time), savings to the economy could total approximately 1.5-2 billion rubles.

The variety of available merchant shapes is expanding comparatively slowly. According to the approximate calculations of experts, the requirements of the branches and sectors of the economy in these products are running ahead of production by 50-100 percent. In order fully to meet the requirements of machine building, for example, it would be necessary to put into production more than 800 new structural shapes. One shortcoming of the product mix of simple structural shapes is the limited number of size graduations, which leads to overconsumption of metal (2.5-15 percent goes into chips)[2] or to increased metals input of machines and structures, and diminishes societal labor productivity. An increase in the number of intermediate rolled product sizes would make it possible substantially to increase metal savings in its consumption.

On the whole we must note that there is inadequate production of economical rolled sectional shapes: merchant shapes and high-precision shapes, and curved shapes -- employment of which in place of conventional products reduces the weight of workpieces and finished products. General and special-purpose merchant shapes are more economical. Only half of the entire number of merchant shapes (970) are produced in lightweight versions.

Reduction in the metals requirements of machinery depends in large measure on utilization of rolled products made of low-alloy steels, heat-treatment hardened, coated, plated and clad, special and lightweight merchant shapes. For the most part hot-rolled commercial carbon steel is employed in the nation's economy (75 percent), steel which many times fails to meet the elevated demands on modern materials, especially as regards strength. Much more effective are low-alloy steels which are stronger than carbon steels and which possess good plasticity, toughness, weldability, and resistance to corrosion.

An important means of ensuring the durability of machinery and metal savings is a systematic increase in the quantities of manufacture of rolled stock with various types of coatings, platings, and claddings, and heat-treatment hardened. Losses to corrosion comprise approximately 10 percent of iron and steel production. A large percentage of rolled stock is produced without suitable hardening treatment, while heat treatment of hot-rolled carbon and low-alloy steel makes it possible significantly to increase its strength. Plastic-coated sheet and sheet aluminum are produced in insignificant quantities. The economic effectiveness of consumption of heat-treatment hardened rolled stock, coated, plated and clad rolled products and rolled stock of low-alloy steel ranges from 20 to 60 rubles per ton in calculated outlays. Machines and structures made of such metal are stronger and lighter, are longer-lived, while metal consumption and the metals requirements of products are reduced. For example, products made of galvanized sheet last approximately two to five times as long as items made of untreated sheet. Requirements in these rolled products are considerably greater than volume of production.

In order to improve the structure of metal and rolled stock and to improve their qualitative characteristics, it is necessary to conduct a number of measures together with optimization of the organizational structure of ferrous metallurgy and primary processing production in the machine building industry. Simultaneous adoption of advanced directions in the production and consumption of metal and improvement in technological level not only in the producing but also in the consuming branches ensure conditions for fullest utilization of reserve potential for achieving metal savings. Let us examine some of these areas.

Considerable influence on improving the technological level of metallurgical production is exerted by accelerated development of steelmaking in oxygen converters and electric furnaces, out-of-oven degassing and continuous steel casting, and extensive adoption of modern, high-output equipment capable of ensuring the requisite quality of metal products. Possibilities of intensification of ferrous metals production depend in large measure on the structure of capital investment in the iron and steel industry. It is advisable to increase the percentage share of capital spending in rolling-mill production, including on improving quality and expanding the variety of rolled products.

Precision casting and stamping methods, welding and rolling parts, and powder metallurgy methods, that is, low-waste and no-waste methods of manufacturing machine and equipment parts are promising areas in the development of metalworking technology. Mechanical working of metal by cutting still predominates in the machine building industry, however, which leads to considerable metal waste in the form of chips and increases metals input, labor intensiveness and the capital-to-output ratio of production. What is needed is standardization of manufacturing processes and development of optimal technologies in the initial processing shops of the machine building industry. The structure of manufacturing processes should be planned according to materials labor intensiveness. It is essential to perform analysis of machine structural designs and processing in a planned and systematic manner, in order to determine reserve potential for achieving metal savings and to expand the scale of utilization of advanced structural materials. Improvement in the technical and organizational level of metalworking technology is one of the important ways to achieve savings in metal.

An insufficiently high degree of specialization and concentration of initial processing production in the machine building industry is holding back the adoption of high-output resource-conserving equipment and efficient manufacturing processes. It is advisable to plan specialization indices for intensive development of the centralized production of castings, forgings, etc. A long-range specialization and co-production plan for the various machine building branches should also be drawn up, including the manufacture of castings, forgings and other initial-process items. Capital investment must be allocated precisely to these specialized production operations, not into expanding initial processing shops at machine building enterprises or for building combined plants.

Efficient utilization of metals and a decrease in production metals input depend on the scale of employment of a number of structural materials used in place of metals. Plastics are widely employed in all branches and sectors of the economy. Plastics consuming branches have developed advanced, lighter-weight structures with employment of polymeric materials in place of ferrous and nonferrous metals. The level and rate of development of the chemical industry, however, do not yet ensure technical and economic possibilities of consumption of these efficient structural materials, both in production volume and in qualitative characteristics. Production volumes of plastics, especially modern structural thermoplastics and glass plastics, are still inadequate. Prices on structural plastics and synthetic resins remain high.

All this is hindering expansion of the scale of employment of structural polymeric materials and decrease in production metals input. The requirements of the machine building branches in plastics are being met by 65 percent on the average, while this percentage is lower for certain types of plastics. An increase in the production volumes of structural plastics, especially with enhanced characteristics, which are capable of competing with ferrous and nonferrous metals, improvement of the technical and economic characteristics of plastics production and decrease in the production cost of plastics will ensure conditions for reducing not only production metals input but also the weight of machinery and equipment.

Obviously in the future we should plan accelerated development of structural plastics and more intensively improve the technical base for their production and intrabranch structure. The structure of plastics production should be planned in such a manner that they are utilized primarily in those industries where they generate the greatest effect. Branch technical and structural policy should be focused toward this.

One promising substitute for ferrous metals is aluminum, which is characterized by excellent physical-mechanical properties and corrosion resistance, low specific weight, good decorative qualities, and effectively replaces steel and heavy nonferrous metals, substantially reducing the weight of machines and equipment. Transport machine building is the most effective area of employment of aluminum alloys. A priority rate in the production and consumption of aluminum has become one of the characteristic features of technological progress. In our country the growth rate of aluminum in recent years has been running ahead of that of ferrous metals.

Achieving savings in metal on the basis of improving the technical and organization level of enterprises depends in large measure on indices specified in production plans. The present system of planning, evaluation and economic stimulation of production in tons and in volume of product sold leads to the manufacture of heavier and more metals-requiring rolled stock and equipment. L. I. Brezhnev noted at the November (1981) CPSU Central Committee Plenum that we have not yet succeeded in eliminating indices which essentially encourage waste. He was referring to the vaunted "gross" in tons or rubles. Enterprises have no incentive to manufacture new, lightweight rolled sectional shapes or lighter-weight machines, since their manufacture worsens an enterprise's technical-economic performance indices -- volume of sold production and labor productivity decline. In the iron and steel industry the labor intensiveness and capital-to-output ratio of high-quality product are frequently increased, since these products require additional processing. All this has a negative effect on material incentive funds.

The system of measures to achieve further improvement of plan and evaluation indices specified by the CPSU Central Committee and USSR Council of Ministers decree entitled "On Improved Planning and Strengthening the Effect of the Economic Mechanism on Improving Efficiency of Production and Work Quality" is being implemented slowly and not in all branches. Incentive for economical utilization of material resources is provided by planning such indices as standard net production and sales volume taking into account meeting product sales deliveries on the basis of contracts and sales orders. It is essential to plan an expanded product list in units of measurement which more fully characterize product use properties.

New indices should be reflected in prices and technical-standards documentation. Product materials intensiveness indices were taken into consideration to a greater degree than previously in elaborating the wholesale prices which became effective in 1982, which makes it possible to intensify the incentive role of prices in economizing in material resources. Planning and production incentive for certain types of equipment, however, are expressed in tons. The ton also remains the principal planning and evaluation indicator in ferrous metallurgy, since on the basis of tonnage it is easier to fulfill the plan by increasing volumes of ordinary-grade rolled stock. We should note that experiments are being conducted in the iron and steel industry on planning and record keeping on certain types of rolled stock and rolled product in meters, square meters, and theoretical weight. It is advisable to expand approval of indicators which most fully take the quality of metal into account. Metals input and standard weight of product items characterize economy both of their production and consumption. Obviously this indicator should become mandatory in designing structures and manufacturing processes and when putting new or modernized product items into production. There is not yet adequate economic incentive, however, for designers and engineers to develop less materials-intensive products. Insufficient attention is also being devoted to reducing material intensiveness of products at machine building enterprises. This is due to the fact that according to existing regulations an item is put into production if it meets all requirements imposed on it other than the requirement of reduced materials intensiveness. Nor is a high level of materials intensiveness an obstacle in awarding a product the Seal of Quality.

An important role in overcoming these deficiencies will be played by implementation of measures, specified in the decree on economizing in material resources, pertaining to further improving standards and technical specifications and enhancing their role in improving product quality and in economical utilization of materials. Now principal product characteristics incorporated into standards and specifications will include indicators of a product's materials intensiveness and energy requirements, corresponding to the finest achievements of Soviet and foreign science and technology. On certification, a product can be assigned to the top quality category only if these requirements are satisfied.

In order to implement measures specified by the decree pertaining to economical utilization of material resources, it is essential to make appropriate changes in organization of accounting and record keeping pertaining to indices characterizing efficient utilization of material resources. In particular, there should be established a technically substantiated standards base for the major material resources, for all metals, as well as for the principal machine building products. Until recently only savings in hot-rolled metal was planned. Many machine building products are not covered by standards. As a result, for example, castings production and consumption volumes unwarrantedly grew and, correspondingly, the percentage share of castings in the total metal structure was declining slowly. This was impeding the progress of reduction in weight of machines. In addition, consumption standards are not always revised with the adoption of scientific and technological advances. Planning of targets pertaining to an average decrease in specific consumption for steel and iron castings and forgings from ingots, as well as a rolled stock utilization factor was adopted effective 1981. This should provide incentive for more efficient utilization of all metal.

The decree specifies establishing, beginning in 1983, for industrial, construction and transport ministries, associations, enterprises and organizations production cost targets in five-year and annual plans, including a ceiling on material outlays in monetary terms per ruble of output. Consumption standards for the major types of materials, fuel and energy will be established in physical terms per unit of output. The list of material resources on which centralized targets pertaining to average decrease in consumption standards are established will be expanded. In order to carry out the planned measures, it is essential to improve the standards operations of enterprises. Existing standards on consumption of raw materials, supplies, fuel and energy resources should be promptly revised and new ones established proceeding from plan targets, taking into account adoption of scientific and technological advances.

A number of scientific research institutes have begun implementing these measures. In particular, NIIPiN [Scientific Research Institute of Planning and Standards] under USSR Gosplan is preparing a list of the most important materials-intensive products and material resources, is drawing up standard methods for calculating technically and economically substantiated standards and for planning the materials intensiveness of products, and is drafting a standard regulation on organization of bonus payments for achieving savings in material-technical resources and reducing the materials intensiveness of products manufactured.

Of great importance for efficient utilization of materials is a balance between production and consumption of all types of resources and the availability of an optimal central reserve of these resources. A shortage of certain types of rolled products and ceiling-limited distribution of ferrous metals are forcing enterprises to incorporate reserves into consumption standards for principal product items. Enterprises are essentially creating "their own" internal reserves for meeting various additionally occurring needs, including compensating for losses due to production-line rejects, which leads to inefficient utilization and freezing (accumulation) of certain quantities of material resources at enterprises and the development of a short-supply situation for certain metal products.

At the stage of plan drafting, ministries should determine actual requirements in all types of rolled products and capabilities to meet these requirements. Essential for this is elaboration of a balanced metals production and consumption plan. For proportional and balanced development of the economy, when drawing up national economy economic and social development plans it is essential to specify centralized material reserves. Their formation will promote an end to scattering of materials among separate agencies and enterprises and will create the possibility of selection of necessary materials and their more efficient utilization.

The decree on economizing in material resources acknowledges as essential increased incentive for workers, managers, engineers, technicians and office employees of associations, enterprises, and organizations to achieve efficient utilization of material resources. Obviously a uniform system of material incentive to economize should be created. Economic incentive funds of ministries and agencies, associations, enterprises and organizations will be formed in relation to the level of material outlays per ruble of product (work performed) and total savings achieved by reducing material outlays in comparison with the ratified ceiling. Workers, foremen, process engineers, designers and other engineer-technician personnel will be awarded bonuses for achieving savings in specific types of material resources in comparison with the specified technically substantiated consumption standards. Payment of bonuses to administrative office personnel at production associations, enterprises and organizations would be in relation to the level of material outlays per ruble of product in comparison with the established ceiling, taking into account fulfillment of targets pertaining to product cost for the association, enterprise, and organization. Implementation of all these measures will serve as a basis for establishing a uniform system of incentive to economize in resources.

Economical utilization of material resources will be promoted by converting over all branches of industry to planning a sales volume indicator taking into account completion of production deliveries according to the full list and variety. When figuring the material incentive fund, one should take into account the levels of materials intensiveness of product items and fulfillment of contracts pertaining to delivery schedule, product quality and variety. It is advisable to increase the amount of fines and to increase the personal liability of officials of enterprises, ministries and supply personnel for failure to meet contractual agreements.

In our opinion the above-examined areas of reducing production metals input and achieving efficient metals utilization, particularly optimization of the branch structure of metals consumers and improvement in the structure of structural materials will foster economical utilization of material resources.

FOOTNOTES

1. See A. I. Tselikov, "Metallurgicheskiye mashiny i agregaty: nastoyashcheye i budushcheye' [Metallurgical Machinery and Equipment: Present and Future], Izdatel'stvo Metallurgiya, 1979, page 136.

2. See N. F. Sklokin, "Ekonomicheskiye problemy povysheniya kachestva i razvitiya sortamenta chernykh metallov" [Economic Problems of Improving the Quality and Enlarging the Variety of Ferrous Metals], Izdatel'stvo Metallurgiya, 1978, page 138.

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ECONOMY OF METAL THROUGH HIGHER QUALITY METAL

Moscow METALLOVEDENIYE I TERMICHESKAYA OBRABOTKA METALLOV in Russian No 5, May 82 pp 2-6

[Article: "An Increase in the Quality of Metal - the Real Means of Its Economy"]

[Text] The economy of metal is one of the key problems of modern machine building. Under conditions of the improvement, expansion and optimization of the existing production, the rational use of metal becomes very important. Therefore, in the "Basic Trends in the Economic and Social Development of the USSR for the years 1981-1985 and for the period up to 1990" together with the formulation of the scientific and technical problems, the solution to which allows obtaining a considerable savings of metallic materials, the need for implementing another, more effective means is underlined: the zealous use of metal in the process of its processing, economical with respect to the national good. "...We, of course, will put new metallurgical plants into operation. But to overcome the shortage of metal, there exists another means, a more skillful and complete use of that which is produced," said L. I. Brezhnev at the 26th CPSU congress [1]. This is a practical embodiment of the Leninist thought about the fact that communism begins with the everyday care of the workers concerning each pood of metal and grain and the increase in the labor productivity.

If we bear in mind the problems of the economy of metal which arise from the first trend, the improvement of production based upon new scientific and technical achievements, then, first of all, we need to know the feature which is characteristic for it: these problems are essentially complex. They can be solved effectively only under the condition of the economy of materials in all links of the industrial chain of manufacturing a part, beginning with the smelting of the metal and ending with finishing operations, i.e., it is necessary at the same time to seek the means of the economy of metal in the reserves which are available in metallurgy, in machine building, in particular, in metal working, and so on. The greatest savings of materials can be achieved in solving basic problems of the modern production of products: an increase in the quality of the metal; improvement of the metallurgical conversion; the development of powder metallurgy; an increase in the corrosion resistance of materials; the development of new strcutural steels and alloys; the improvement and development of new forms of heat, deformation and chemical-heat treatments; and the introduction of low-waste technology.

The increase in the quality of the metal is the basic way to increase the life of the parts and one of the main sources of the economy of steels and alloys. Therefore, the development of ferrous metallurgy in the trend of the improvement and creation of methods of production, which provide an increase in the quality of the smeltable materials, is, at the same time, one of the means of the economy of metal. In the 11th Five-Year Plan there will be further development in electric-furnace steel smelting and oxygen-conversion production with and increase in the smelting of steel by 1.6 and 1.3 times, respectively, [1], plasma smelting, and also processes of electric-slag, vacuum-arc, vacuum induction, and electron-beam remeltings [2]. The portion of the metal scrap and waste products of ferrous metals will be considerably increased in the charge. For example, in the smelting of electric-furnace steel, the quality of it will consist of more than 95% of the w ight of the whole charge, and in the total volume of steel production the portion of metal scrap exceeds 44% [3]. There is much interest in the smelting of steel with the use of metallized pellets as the charge. which was developed at the Oskol'sk electrometallurgical combine. In the next five-year plan, the production of large tonnage forms of metallurgical production with reliable and stable normalized quality characteristics will be carried out. In the first place, it is necessary to ensure an increase in the uniformity and purity of the metal with respect to harmful impurities: a decrease in the content of sulfur and phosphorus down to thousandths of a percent. This makes it possible to increase considerably the ductility at low temperatures of the alloyed high-strength and low-alloyed steels for gas and oil pipelines, building structures for the northern regions and so on. The large-tonnage production of such metal will be possible because of the intensive development of the extrafurnace methods of refining. The volume of steel refined by degassing is increased by 3.2 times, by inert gases, 1.4 times, and by synthetic slags, 1.3 times. Thus, for example, the use of vacuum processing of electric (sheet) steels in the ladle at the Cherepovets metallurgical works made it possible to increase considerably the output of high-quality steels and, furthermore, to lower the cost of one ton of a cold-rolled sheet by 18-20 rubles [4]. The refining of steel also permits reducing the consumption of ferroalloys, decreasing the rejects of metal with respect to chemical composition and defects of the surface of the rolled stock, and stabilizing the properties of steel from smelting to smelting.

The improvement of the metallurgical process stage is one of the trends which provide a considerable economy of the materials without an increase in the volume of its production. The main effect is reached due to the production of efficient forms of metal production and the introduction of new progressive industrial processes, which improve the structure and complex of mechanical properties of the metal.

In the first case the most promising are works on the optimization of the dimensions, the increase in precision of the rolled stock and pipes, the expansion of their grades (for the purpose of equipping the customer with materials with minimal deviations of the dimensions from those required), and also the creation of fundamentally new deforming devices, for example, part-rolling mills which allow making by plastic deformation either the parts directly or blanks having the configuration of parts, with minimal allowances for machining. At present, ferrous metallurgy in the USSR produces more than 7,500 merchant, shaped roll-formed and high-precision section dimensions of rolled stock, sheet rolled stock - 22,000 dimensions, steel pipes - 30,000 section dimensions, and metal hardware - 50,000 forms [2]. In recent years about 900 state and dozens of branch standards and 5400 specifications for producible production have been renewed. About 300 obsolete and heavy sections are excluded from the assortment, and requirements for deviations from the assigned dimensions are tightened. In spite of the fact that only in the last five years there has been the development and assimilation of metal production of a large range of products (rolled stock of 870 new progressive section dimensions, including 339 hot-rolled shaped, 283 roll-formed and 248 shaped of high precision), during years of the 11th Five-Year Plan there will be an increase in the production of roll-formed section of 1.5 times, of wide-flange beams 1.2 times, and of sheet cold-rolled steel 1.5 times [2]. The maximum economy of metal is achieved in precision forging and rolling in a field of negative and narrowed tolerances. For example, as a result of rolling in a field of negative tolerances, at the "Azovstal'" plant, the Donetsk, Western Siberian, Cherepovets Novo-Lipetsk, Chelyabinsk, and Taganrog metallurgical works, the Dneprovsk metallurgical works imeni Dzerzhinsk, and the "Amurstal'" plant, more than 34,000 tons of metal are saved [5]. Extremely efficient is the introduction at the wire, light-section and medium-section rolling mills of preliminarily stressed stands (PSS), which makes it possible to produce rolled stock of high precision. Here the microstructure and properties of the metal are improved, losses to scale and the thickness of the decarbonized layer of the rolled wire are decreased, and the specific quantity of metal of the structures is lowered. The national economic effect resulting from the introduction of a new system of stands, at the Cherepovets metallurgical works alone was about 60 million rubles. In the 11th Five-Year Plan the PSS will be installed at the light-section mills of the Western Siberian and Chelyabinsk metallurgical works and the "Krivoy Rog" plant [5]. A considerable reserve in the economy of metal is the putting into production of progressive industrial processes based on the most recent achievements in science and technology, for example, the manufacture of machine-building parts by the method of rolling. About a hundred part-rolling mills are already operating in our country. An increase of 4-5 times in their number makes it possible not only to save 350,000 tons of metal yearly, but also free about 20,000 metal-cutting machines and 27,000 workers. The total savings amount to about 400 million rubles per year [6]. Thus only owing to the development of progressive methods of producing rolled stock of steel pipes and metal hardware, will about seven million tons of metal be saved in 1985.

The second trend of works on improving the metallurgical process stage permits obtaining an economy of metal owing to an increase in the complex of its mechanical properties. The successful development in this trend in the next five-year plan, in the first place, is determined by the results achieved in the 10th Five-Year Plan in the field of applied and theoretical physical metallurgy and the theory and practice of heat and deformation treatments. The basic means for increasing mechanical properties of metal is the regulation of the temperature-rate parameters of processes of the deformation of ingots in their treatment and the combination of plastic deformation with heat treatment. To achieve the maximum economy of metal, it is necessary to conduct extensive studies on the finding of efficient industrial schemes of heat and heat and strain hardening with the appropriate alloying of steel. Deserving special attention among these schemes are: the hardening of the rolled stock by heat treatment from special or milling heating, monitorable rolling, heat treatment from the intercritical temperature range, the use of TMT [Thermomechanical Treatment] in the production of rolled stock from steels with perlitic conversion, and thermocyclic treatment. For example, thermal hardening from milling heating in the flow of the mills, based on the theory of the thermomechanical effect on steel and a technology worked out in each specific case with the use of simple devices for the cooling of the steel from the deformation temperature, permits a saving on the avaerage of 22% of the metal and the obtaining in the national economy of an economical effect of about 38 rubles per ton [7]. During 1981-1985 an increase in the production of such rolled stock of 1.8 times will be provided. The monitorable rolling of the low-alloyed steels, carried out with high degrees of deformation at comparatively low temperatures, ensures an increase in their strength and plastic properties. The putting into operation of the 3000 mill at the Il'ich metallurgical works permits the rolling additionally in monitorable modes up to two million tons of plate per year [2]. The implementation in future years of rolled stock by monitorable modes and different schemes of heat and thermomechanical treatments will provide not only a saving of the metal, but also a considerable saving of the alloying elements, since with such methods of treatment it is possible to use economically alloyed materials. As a result of the improvement of the metallurgical process stage in all links, by 1985 there will be an assimilation of the technology of the production of sheet and section steel and pipes with an ultimate strength of 700-2500 MPa, and the average strength of the metal will increase by 5%-6% as compared with that reached in 1980 [2].

The powder or "little" metallurgy in the 11th Five-Year Plan should provide a considerable economy of steels and alloys because of the high utilization factor of the metal. In the production of each thousand tons of products by such method, a savings of 2.5 thousand tons of rolled stock will be achieved. The effect of the savings, first of all, depends on the volume of production of the high-quality iron powders and also powders from alloyed steels and alloys, and, therefore, by 1985 it is planned to increase the production of metallic powder by 3.3 times. To do this, it is necessary to concentrate the scientific studies in the direction of obtaining iron powders by the method of the spraying of melts by high-pressure water and the method of restoration of the ores and hydrogen superconcentrate and of the obtaining of pure iron oxide and iron powders of higher quality from the depleted hydrochloric-acid etching solutions of the rolling production. From these powders it is planned to manufacture products with increased wear resistance, life, corrosion resistance, and other special properties. This requires the development of new heat-resistant and corrosion-resistant alloys on the basis of intermetallic compounds and refractory metals and the improvement of processes of the application of heat-resistant, wear-resistant and anticorrosion coatings by the gas-thermal and ion-plasma methods. There is increased interest in powder composite materials, and the use of these materials allows saving not only the scarce alloying elements, but also the special expansive steels. For example, the replacement on just one centerless lathe of rollers of hardened steel R6M5, which feed and hold the bars to be machined, by rollers of sintered alloy, titanium carbide and stainless steel, makes it possible to increase the resistance by 15-20 times and obtain an annual savings of five to six thousand rubles [11].

The increase in the corrosion resistance of materials is one of the most important problems of modern physical metallurgy, the successful solution to which is governed by the effectiveness of combatting corrosion, which brings losses in the billions of rubles to the national economy. The basic studies are conducted in the direction of development of fundamentals of the alloying of new corrosion-resistant steels and alloys and the creation of polymer and metallic coatings with the minimal use of expensive and scarce metals and, namely, anticorrosion coatings for parts of machine-building production and coatings for pipes.

In the development of new materials, the principle importance is in works on the optimization of the composition of complexly alloyed steels and alloys for the purpose of reducing the consumption of scarce metals, for example, nickel, the investigation of the effect of alloying elements and impurities on the structure and corrosion resistance, and the creation of new alloys with increased corrosion resistance. The use of coatings, especially polymer, is one of the promising trends in the protection of metal from corrosion. The combination of the steel base and polymer coatings permits creating new structural materials with assigned properties, including resistance in different chemical media, and thermal and sound insulation materials with good stampability and a commercial form. At the present, TsNIIChERMET [Central Scientific Research Institute of Ferrous Metallurgy imeni I. P. Bardin], jointly with a number of institutes of the chemical industry, is conducting works to create a new corrosion-resistant and salt-tolerant material for the automotive industry of the type "Tsinkrometall" [2]. Of the known methods of applying metallic coatings, a special place is occupied by vacuum chromizing (VC), the technology of which has been developed by UkrNIISPETsSTAL' [Ukrainian Scientific Research Institute of Special Steel] in collaboration with a number of metallurgical works of our country [8]. This technology has certain advantages over other methods of the application of coatings. For example, a diffusion layer 100-200 μm thick with saturation in a vacuum is formed in 3-5 minutes; to obtain a similar coating by gas or powder methods 28-36 hours are required. Such a high rate of the formation of the diffusion layer is caused by the special feature of the very process of the VC: the metallizing spray gun is vaporized in the heating process in a vacuum, and its vapors precipitate onto the surface of the article heated above 700°C. Under these conditions an effective diffusion saturation of the surface layers of the metal occurs. The metal rolled stock (sheets, pipes) with coatings applied by this method has practically the same resistance at increased temperatures as do the corrosion-resistant steels Kh18T1 and 10Kh13 and, in individual cases, as austenite steels of the type 18-10, i.e., after such treatment the standard rolled stock can be successfully used instead of the more expensive and complexly alloyed steels. A thin chrome-plated sheet, with respect to corrosion resistance, is equivalent to a bimetal, and its net cost is considerably lower. The VC of boiler pipes, in the retention of high heat resistance, allows increasing by 2-4 times the resistance of gas corrosion, increasing the reliability of operation of high-pressure boilers and considerably reducing the number of major repairs [8].

Other methods of applying coatings are of great importance. Thus a process which is progressive is the industrial process of the production of a hot-aluminized thin sheet - a corrosion-resistant, weatherproof and heat-resistant structural material, the application of which in the construction industry allows increasing by three times the life of the structures as compared with hot zinc-plated metal [2].

Special attention in the problem of the economy of metal is being given to the protection of pipes from corrosion: a decrease in their thickness even of several percent makes it possible to save a significant quantity of steel and alloys for the national economy. Thus the use of glass enamel coating of pipes for heat simultaneously with an increase in the period and service of five to six times allows decreasing the thickness of the wall of the pipes by 30% to 40% and sharply reducing the consumption of metal [9]. The application of the method of applying coatings developed in the UralNITI [Ural Scientific Research and Technical Institute] at the Sokolovsk-Sarbay mining combine, with a yearly productivity of the section of 5000 meters of pipes 377 millimeters in diameter, ensures an increase in the resistance of the pipes of 10 times [9] and a savings of 150 rubles from the use of each meter of pipe. A large saving of metals is achieved in the production of multi-layered pipes. In this case the fundamental importance is acquired by the metal physical problems of producing high-strength rolled steel, beginning from its smelting and ending with the development of the technology of deformation and heat treatment. Showing promise is the modern technology of smelting steel in oxygen steel-making converters, which ensures the possibility of obtaining the content of alloying elements in narrow limits, the uniformity of the structure and mechanical properties of the rolled stock, and the possibility of using the best possible conditions of the milling being monitored.

The development of new structural materials is a fundamental problem of modern physical metallurgy, and the successful solution to it, first of all, depends on the economy of steel and alloying elements. The creation of new materials in the near future will be accomplished mainly in the same directions as that of the 10th Five-Year Plan [10]. The main effect of the economy can be achieved as a result of the development of economically alloyed steels and alloys possessing an increased complex of physical and mechanical properties: low-carbon steels alloyed by abundant elements (Mn, Si, Cr), low-carbon steels with carbonitride hardening, martensite-aging economically alloyed steels, and low-carbon steels of the ferrite-martensite grades. A considerable savings can be obtained as a result of the creation of new materials intended for the introduction of highly effective methods of treatment, for example, cold die forging, and the use of them in special operating conditions in regions of the Far North. In connection with this, there is interest in works on the introduction of economically alloyed steels for gas pipelines, which operate under a pressure of 100 at, and highly cold-resistant steels (down to -120°C) for reservoirs and building structures [2]. For the operation of the pipelines at increased pressure, it is necessary to develop steel with a higher complex of properties than is used for this steel 09G2FB. The new steel should possess increased impact strength and strength at -15°C to -20°C with good weldability. The creation of such a material is possible with the collaboration of metallurgists and metal scientists, since to do this it is necessary to develop the technology of smelting steel with narrow limits of the content of the alloying elements, with an ultralow content of sulfur (not more than 0.003% to 0.004%) and completely globularized sulfides, and also with a reduced content of hydrogen; the conditions of monitorable milling for sheets of large thickness (22-24 mm); and the technology of the production of pipes, which ensures a high reliability of the basic metal and welded joint, and an effective corrosion coating for pipes. The technology for obtaining rolled stock and pipes from steels with nitride-vanadium hardening will be assimilated in the next five-year plan. Structural steels which are resistant to sulfide embrittlement will be used in the 11th Five-Year Plan for pipes of petroleum grade and apparatuses for processing natural gas. Also fundamentally important are works on the testing of weldable steels with σ_B = 800-1000 MPa for the manufacture of machine building parts and parts of building constructions and also works on the development and introduction of high-strength steel for welded housings of new atomic energy plants.

The improvement and development of new forms of heat, deformation and chemical-heat treatments are efficient means in the economy of steels and alloys. This is conditioned by the fact that from year to year the portion of the metal (semifinished products and parts) being subjected to strain-hardening treatment is increased in the total volume of production. Simultaneously with an increase in the complex of mechanical properties and structural strength, new methods and progressive industrial processes make it possible to improve the quality of the output production and, consequently, increase the reliability and life of the essential parts of different structures. Promising works in this direction can belong to the development of different plans for obtaining heat-hardened rolled stock; the extensive use of methods of heat treatment based on the use of currents of a high and industrial frequency for heating; heat treatment (heating) in protective atmospheres and a vacuum; and the laser treatment of metals. In the 11th Five-Year Plan the most promising are works in the field of TMT [Thermomechanical Treatment], in particular, the introduction of HTTT [High-Temperature Thermomechanical Treatment] by quasi-hydroextrusion and high-temperature gas extrusion [2]. Finding application in industry are different industrial schemes of treatment by explosion of steels of the martensite and austenite grades, which provide an increase in the ultimate strength above 2000 MPa with a retention or increase in the ductility.

In the field of chemical and heat treatment (CHT) processes which allow obtaining diffusion layers of high quality and, ultimately, increasing the life of the parts will be developed. Belonging to these processes, in the first place, can be different forms of low- and high-temperature processes of Chemical-Thermal Treatment: cyaniding, cyanidation, carbonitriding, short-term nitriding, and others. There is special interest in chemical-thermal treatment at increased temperatures in a vacuum, and when this is carried out it is possible to effectively act upon the structure of the diffusion layer through the change in the pressure and improve the quality of the products through the elimination of internal oxidation.

The introduction of low-waste technology. At present in the creation of new methods of the treatment of materials, beginning with the smelting and ending with the manufacture of a part, it is necessary to strive for the development of low-waste technology. This is one of the main sources of the economy of metal. For example, already for several years the collective PO ZIL [Planning Department of the Moscow Automobile Plant imeni Likhachev] has been carrying out a long-term program for introducing low-waste technology, as a result of which tens of thousands of tons of metal have already been saved [6]. A considerable importance in this article of economy is occupied by problems of the lowering of the specific quantity of metal of the structures and the increase in the utilization factor of the metal [6]. In connection with this, special significance is acquired by the combined development by metal scientists, metal physicists and mechanical engineers of methods for evaluating the structural strength for the purpose of optimizing the strength safety factors in the calculation of structures operating in different temperature-rate loading conditions. In spite of the fact that in this direction certain achievements have already been made (determination of the destructive strength of materials and components of impact strength, the plotting of serial curves, and so on), on the whole the problem remains unsolved. There is fundamental importance in the studies of the connection of the structure with structural strength, the classification of factors determining the brittle and ductile failure, and the creation of universal criteria for estimating the structural strength.

The main efforts in the creation of new machines and assemblies are directed at the lowering of their weight in calculation per unit power. For example, 89 of the 128 most important products being produced by the machine-building works of the Sverdlovsk Oblast have a lower specific metal content than similar Soviet and foreign specimens [6]. However, as Comrade L. I. Brezhnev noted, "...the specific quantity of metal of many machines and equipment being produced remains excessively high. The amount of waste in metal working has not been reduced. Precision billets are slowly being introduced." In connection with this, the basic problem lies in the creation of such processes of treatment which will ensure the obtaining of a utilization factor of the metal of higher than 0.72-0.73 [6].

The measures outlined for improving the quality of metal, the increase in the complex of its physical and mechanical properties, and also the improvement of designs of machines and the technology of metal working and a more extensive use of metallic and polymer materials make it possible to save eight million tons of rolled stock in machine building and two million tons in construction [4]. Such a result can be reached only if the competition for the saving of metal takes on an even wider scope, and if in each labor collective, as is required by resolutions of the November (1981) Plenum of the CC CPSU, results of its work will be analyzed, and reserves for the successful implementation of the production assignments will be put into operation.

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NONFERROUS METALLURGY

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EXTRACTION OF COPPER, NICKEL AND COBALT WITH SEVERAL OXYOXIMES

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[Article by V. F. Travkin, V. V. Yakshin, V. S. Ul'yanov, A. M. Mirokhin and I. V. Belyayev]

[Text] Hydrometallurgical methods are the principal methods employed in processing low-grade off-balance sheet as well as difficult-to-beneficiate oxidized copper ores. In the past these ores were processed according to the scheme leaching-cementation, while in recent years extraction methods of recovering copper from leaching solutions have been in increasingly widespread ue. This became possible in connection with the development of Lix, SME-529, Acorga, and Kelex type reagents [1-3], which are used for selective extraction of copper from weakly acid solutions.

Copper extracting agents belonging to the category of oxyoximes -- OMG [4], ABF [5-7], and others -- have been developed in the USSR. Of these extracting agents, alkylbenzophenonoxime -- ABF -- which has gone through full-scale tests and has been recommended for commercial adoption [8] -- has been studied in the greatest detail.

In spite of the fact that extraction methods are already being employed in the copper industry abroad, the search for new, more efficient and cheaper reagents is continuing. Of considerable interest, for example, is an evaluation of the influence of the structure of an oxyoxime on its extraction properties. For example, introduction of a chlorine atom into the molecule of the Lix 70 reagent has the result that copper extraction can be accomplished from more acid solutions ($pH \approx 1.0-1.5$). It therefore was of interest to examine the properties of alkoxyoximes containing an oxygen atom, which can increase the stability of the copper complex with the oxyoxime (AOBF-1 and AOBF-2). Finally, the presence of two oxyoxime groupings in the extracting agent molecule can lead to an increase in the copper extracting capacity of the extracting agent (OKFO).

In this article we shall examine the extraction properties of the following reagents, which are members of the class of oxyoximes:

4-alk (C_7-C_9) oxy-2-oxybenzophenonoxime (AOBF-1);

4-alk (C_7-C_9) oxy-2-oxyphennaphthenyloxime (AOBF-2);

bis-(4-oxy-5-caprinophenoxime)-2.2-propane (OKFO).

We used specimens of reagents containing not less than 95-97 percent of the principal substance. All reagents are viscous liquids of a dark brown color, with a density of 0.92-0.94 g/cm³. The reagents AOBF-1 and AOBF-2 are readily soluble in kerosene, and the reagent OKFO -- in a mixture of kerosene plus 20 percent octyl alcohol. The viscosity of 10 percent (by volume) solutions of these reagents in appropriate organic solvents was (1.50-1.95) x $10^{-2}m^2/s$ at 30°C. Preliminary tests established that in 2-3 minutes of phase mixing, extraction of copper into organic phase is not less than 90-95 percent.

Of the greatest interest is extraction of copper from sulfate solutions. It is evident from the figures in Table 1 that the tested reagents possess a fairly high copper capacity and selectivity as regards principal impurities, which are not inferior to the properties of ABF reagent. At the same time reagent AOBF-1 is even somewhat superior in these properties to ABF, and therefore we shall subsequently examine in detail the principal properties of precisely this reagent.

Table 1. Distribution of Copper and Impurities During Extraction by 10 Percent (by Volume) Solutions of Oxyoximes in Kerosene (O:B=1:1) and Reextraction by 20 Percent Sulfuric Acid (O:B=1:1)

Solutions	pH	Content, g/l				
		Cu(II)	Fe(III)	Zn(II)	Ni(II)	Co(II)
Initial Refining Agent:	2.01	2.3	0.85	1.72	1.68	0.81
OKFO	1.68	0.76	0.84	1.70	1.68	0.81
AOBF-2	1.66	0.79	0.83	1.71	1.66	0.80
AOBF-1	1.63	0.62	0.84	1.72	1.67	0.81
ABF	1.65	0.67	0.82	1.71	1.67	0.81
Reextract:						
OKFO	-	1.49	0.05	0.05	0.04	0.005
AOBF-2	-	1.56	0.07	0.05	0.02	0.005
AOBF-1	-	1.68	0.04	0.03	0.03	0.005
ABF	-	1.64	0.06	0.04	0.03	0.005

As a rule sulfate solutions for leaching copper-containing ore have a pH of 1.5-3.0. In this case the determining factor in selective separation of copper from iron, as the principal impurity, is the acidity of the aqueous phase. Separation of copper and iron takes place most efficiently when pH=1.0-2.0 (Figure 1).

Removal of copper and iron impurities from nickel electrolyte is a complex technical problem. During extraction with employment of alkoxybenzophenonoxime with pH=5, copper and iron pass into organic phase, while virtually no nickel is extracted. Reextraction of the copper from organic phase is accomplished with a solution containing 150-200 g/l of H_2SO_4, whereby

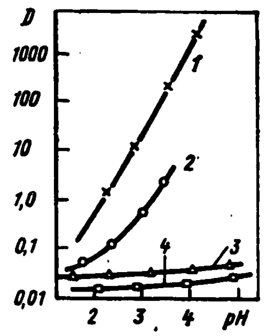

Figure 1. Influence of pH on extraction (D -- degree of extraction) from sulfate solutions -- copper 1, iron 2, nickel 3, and cobalt 4, by AOBF solutions in kerosene. Initial aqueous phase, g/l: 1.2 Cu; 2.0 Fe(II); 5.83 Ni, 0.85 Co

reextracts are obtained, on which electrodeposition of copper can be performed.

Studies have shown that the principal mechanisms of extraction of metals by alkoxybenzophenonoxime from sulfate and sulfate-chloride solutions are similar. Copper is extracted at $pH_{50\%}$ extraction (pH at which K_d=1), equal to 1.2 for sulfate and 1.0 for sulfate-chloride solutions. Extraction of the other metals takes place in the following sequence: iron-nickel-cobalt-manganese-zinc (Table 2).

Table 2. $pH_{50\%}$ Values of Metals in Extraction by a 10 Percent (by Volume) solution of AOBF in Tetrachlorethylene

Metal	Sulfate Solution*	Sulfate-Chloride Solution**
Cu	1.2	1.0
Fe	2.5	2.3
Ni	5.7	4.4
Co	5.8	4.7
Mn	5.8	4.7
Zn	5.9	5.0

* 50 g/l sulfate ion concentration.
** 40 g/l sulfate ion, 10 g/l chloride ion concentration.

In the case of sulfate-chloride solutions, the $pH_{50\%}$ values are displaced into the more acid region. This is probably connected with the existence of chloride or sulfate-chloride groups in such solutions, which are better extracted by oxyoxime than metal sulfates.

Employment of tetrachlorethylene as a diluent prevents the formation of a second organic phase, which is connected with the high solubility of complexes of copper or other metals with oxyoximes in diluents of this type. In addition, employment of this diluent makes it possible to extract metals from more acid solutions than with the employment of a solution of AOBF reagent in kerosene. For example, with extraction of copper from sulfate solutions of 10 percent (by volume) alkoxybenzophenonoxime in kerosene, $pH_{50\%}=1.45$, while in tetrachlorethylene, $pH_{50\%}=1.2$.

Of practical significance is the separation of copper and zinc when they are both present in sulfate and sulfate-chloride solutions. Extraction of zinc and cadmium by oxyoximes, even when $pH \geq 5$, is quite insignificant ($K_d \approx 0.01$), which makes it possible selectively to recover copper from such solutions by extraction. The extraction process can be used to remove copper from zinc electrolytes and to treat copper-chlorine cake in the production of zinc.

Ammonia methods of processing copper- and nickel-containing ore are of interest. Processes of extracting copper [9] and nickel [10] from ammonia solutions with oxyoximes used as extracting agents are in practical use at the present time. One can encounter in industry ammonia solutions with a fairly high content of carbonate, sulfate and chloride ions. Concentrations of copper, nickel, and cobalt in these solutions can vary across a broad range.

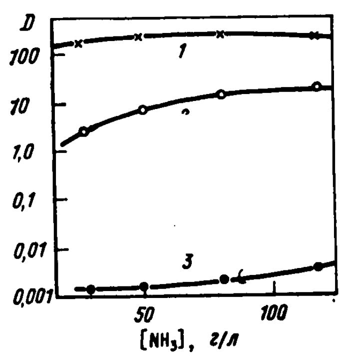

Figure 2. Relationship between extraction of copper 1, nickel 2, and cobalt 3 from an ammonia concentration for an AOBF solution in kerosene.

Aqueous phase, g/l: 1.1 Cu; 3.6 Ni; 1.2 Co; 10 CO_3^{2-}

As is evident from Figure 2, change in ammonia concentration in ammonia-carbonate solutions has practically no effect on extraction of copper, while nickel distribution factors increase from 1 to 10, and extraction of cobalt into organic phase is quite negligible ($K_d \approx 0.002$-0.003). Consequently, selective separation of copper and nickel from cobalt during extraction from ammonia-carbonate solutions is possible. The slight influence of changes of concentrations of ammonia makes the process of extraction of copper and nickel easily controllable.

The concentration of carbonate ion in the aqueous phase has practically no effect on extraction of copper, which is extracted by 10 percent (by volume) AOBF-1 with a high K_d (> 100). Extraction of nickel decreases smoothly with an increase in concentration of carbonate ion: for solutions with a CO_3^{2-} =10 g/1, K_d=10, and for $[CO_3^{2-}]$=60 g/1 -- K_d=1 (ammonia content 50 g/1). Thus in the case of ammonia-carbonate solutions, the separation factors of copper-cobalt and nickel-cobalt pairs are large across the entire range of change in carbonate ion concentration. For example, with a carbonate ion concentration of 40 g/1 and ammonia 50 g/1, β_{Cu-Co}=16,000, and $\beta_{Ni-Co} \approx 350$. This makes it possible selectively to recover copper and nickel from the aqueous phase. Separation of these metals can be accomplished at the reextraction stage. A sulfuric acid solution at a concentration of 50-80 g/1 is used for reextraction of nickel, and 150-300 g/1 for copper.

Extraction of metals from ammonia-sulfate solutions has certain peculiarities. For example, an increase in the ammonia concentration leads to suppression of copper and cobalt extraction, while nickel is extracted by oxyoxime [1] in a fairly narrow range of ammonia concentrations (30-80 g/1), with K_d=2-4. The metal separation factors reach maximum values with fairly low ammonia concentrations (to 40-60 g/1).

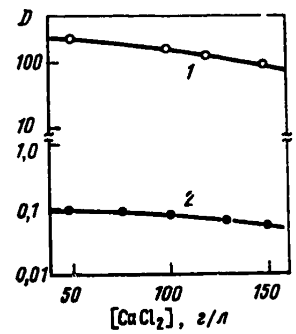

Figure 3. Relationship between extraction of nickel 1 and cobalt 2 from a calcium chloride concentration for an AOBF solution in kerosene. Aqueous phase, g/1: 4.6 Ni; 1.5 Co; 90 NH_3 (bound)

Sulfate ion concentration in the aqueous phase does not greatly affect extraction of copper: $K_d \approx 10$ in the range 50-250 g/1 of sulfate ion. Extraction of nickel increases with an increase in sulfate ion concentration, while extraction of cobalt decreases. Experimental data indicates that with the aid of alkoxybenzophenonoxime [1] one can selectively recover nickel and cobalt from ammonia-sulfate solutions with high sulfate-ion concentrations (>150 g/1) and comparatively low ammonia concentrations (<60 g/1). In these conditions cobalt remains in solution.

Recovery of metals from ammonia-chloride solutions has been examined in the example of nickel and cobalt. With a constant concentration of calcium chloride ($\sim$150 g/1), change in the ammonia content in aqueous phase does not lead to a substantial change in extraction of nickel and cobalt. Throughout the entire investigated range of ammonia concentration (40-120 g/1), nickel distribution factors remain high ($K_d \gtrsim 100$), and cobalt -- low ($K_d \approx 0.1$). This makes it possible to separate nickel and cobalt with $\beta \approx 900$-1000. Calcium chloride concentration also has little effect on the coefficients of distribution of nickel and cobalt (Figure 3). Thus nickel and cobalt can easily be separated with extraction by oxyoxime [1] also in the case of sulfate-chloride solutions.

Conclusions. 1. The high selectivity of recovery of copper from sulfate and sulfate-chloride solutions with the employment of alkoxybenzophenonoxime as extracting agent has been shown.

2. The possibility of separating copper, nickel and cobalt from ammonia-carbonate and ammonia-sulfate solutions by means of extraction by alkoxybenzophenonoxime has been established.

3. Nickel, during extraction from ammonia-chloride solutions, transitions to organic phase with high coefficients of distribution, while cobalt remains in aqueous phase.

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MATERIALS SCIENCE DEVELOPMENTS

UDC 66.017

SOME DIRECTIONS FOR DEVELOPMENT OF MODERN SCIENCE OF MATERIALS

Moscow VESTNIK AKADEMII NAUK SSSR in Russian No 1, Jan 82 pp 47-56

[Article by Ch.V. Kopetskiy, corresponding member, USSR Academy of Sciences, and A.F. Vyatkin, candidate of physical and mathematical sciences]

[Text] The solution of problems related to the creation of materials with given physicochemical and mechanical properties determines the progress being made in many branches of technology and the national economy. In connection with this, there are heightened requirements for the development of the science of materials as a field of knowledge that has been called upon to provide scientific substantiation and practical recommendations for the creation and utilization of new and the production of traditional materials with extremely good characteristics. One of the main goals is to investigate the surface of materials, which has a definite effect on a material's properties and the nature of the processes taking place when articles made from it are being used. The rapidly growing flow of scientific publications in this field has resulted in an extraordinarily broad spectrum of practical problems, the successful solution of which is directly related to understanding the properties of a surface, the progressive development of methods of investigating it, and the emergence of new, highly effective methods for treating both the external and internal surfaces of materials. In this article we discuss several of the areas of investigation in the science of materials that have been developing most actively in recent years.

The traditional object of the science of materials is metal. The knowledge that has been amassed in the field of the science of materials makes it possible to formulate, in particular, the following conclusion: in order to provide metal articles with the best mechanical properties, it is necessary to create a given macro- and microstructure with a controllable chemical composition, including that of any alloyed material; in connection with this, in most cases it is important to have chemical and structural uniformity.

It is a well known fact that a metal polycrystalline aggregate is characterized by a ramified system of internal surfaces; these are the boundaries of the grains, on which intergrain, internal adsorption of impurities--primarily harmful ones--actively develops. In this case, the grains' boundaries obviously become the weakest place in the material. Consequently, for a generally invariable content of harmful impurities in a metal, reducing the size of the grain--that is, increasing the overall area of the grain boundaries--must result in a reduction in the impurity content per unit of grain boundary area and an increase in the material's three-dimensional strength.

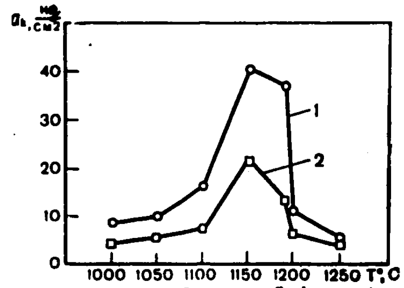

Figure 1. Dependence of impact strength on temperature: 1. after treatment with ultrasound during crystallization; 2. without treatment with ultrasound.

For this purpose we are developing different methods for treating metals that are realized during crystallization from the liquid state and during processing of a metal in the solid state. They include, for example, the use of ultrasound in the zone of crystallization of a steel ingot in continuous casting units, which results in a reduction in the size of the grain that is accompanied by an improvement in the strength characteristics.

Figure 1 depicts the dependence of impact strength a_k on temperature for a piece of steel subjected to such treatment (curve 1) and a piece cast without the use of ultrasound (curve 2). The equiaxial, small-crystal structure that is typical of an ingot treated with ultrasound, instead of the coarse-grained dendrite structure that is obtained by standard technology, provides--as is obvious from Figure 1--a twofold increase in impact strength.

A substantial reduction in grain size in the solid state (for steels, in particular) is also possible when other metal treatment methods--including deformation and recrystallization processes with repeated heating and cooling--are used, because of phase recrystallization (including phase cold hardening during rapid heating). Such treatment proved to be particularly effective for the pipe steels for the main high-pressure pipelines that are used in the northern regions of our country. For instance, the method of cyclic (three or more cycles) heat treatment with heating rates of 10 deg/s and cooling in water after each cycle makes it possible to obtain a material with a grain size of 3-5 µm (13th ball), which results in an increase in impact strength and a lowering of the fracture transition temperature. When 17G1S steel in treated in this way, its impact strength is increased from 6 to 10.5 kg/cm^2 (when tested at -40°C).

In the limiting case, the small-crystal structure can be represented as amorphous. Right now, intensive work is being done to develop different methods for hardening from the liquid state for the purpose of obtaining an amorphous or extraordinarily small crystalline structure. In order to do this, it is necessary to achieve cooling rates of 10^6-10^7 deg/s. The interest in such materials is huge, since they demonstrate new and unique properties. For example, for compounds of the Fe-P-C and Fe-Cr-P-C types, the maximum strength σ_B is 310 and 385 kg/mm^2, respectively, while filaments with an amorphous structure that are made from the alloy $Fe_{60}Cr_6Mo_6B_{28}$ have $\sigma_B \simeq 450$ kg/mm^2 and, in addition, are very hard and resistant to wear[1] (the level of hardness for $Fe_{80}B_{20}$ reaches ~1,100 kgf/mm^2). The mechanical characteristics of amorphous alloys are extraordinarily sensitive to a change in the alloy's composition. For example, replacement of part of the iron in the alloy Fe_{80}-C_7-P_{13} with titanium, vanadium, chromium or manganese leads to an increase in its microhardness from 750 to 850 kgf/mm^2. However, the introduction into the alloy of such

[1] See: Duhay, P., Sitek, I., Prejsa, M., and Butvin, P., PHYS. STAT. SOL., Vol 35(a), No 1, 1976, pp 223-233.

elements as cobalt, nickel or copper results in a lowering of the microhardness values[1] to 650 kgf/mm^2.

The deformation mechanism of such alloys is interesting. When stretched they are subject to brittle failure, whereas during compression or flexure testing a high degree of plasticity is seen. For example, bars made from the alloy $Pd_{77.5}$-Cu_6-$Si_{16.5}$ that are 2 mm in diameter can be rolled into strips that are 0.1 mm thick. The high plasticity of amorphous materials makes it possible to produce deformable tapes from brittle materials, such as Au-Si and Au-Ge solder and other solders used in electronics to join stainless steels and heat-resistant alloys ($Ni_{69}Cr_6Fe_3B_{14}Si_8$).

Rapid hardening from the liquid state, which eliminates segregation effects almost completely, provides both a uniform chemical composition and a homogeneous structure in the solid state. The absence in amorphous metal alloys of defects of the type of grain boundaries, dislocations and so on, which are typical of a crystalline structure and are sources for the origination of corrosion processes, provide these materials with good anticorrosion properties. In the present literature there are description of many experimental facts that note for amorphous alloys either a complete lack of corrosion losses or a reduction in them in comparison with crystalline alloys having the same composition.

The magnetic characteristics of amorphous alloys are extremely good: high magnetic permeability and low coercive force, while the magnetostriction of the saturation of a number of alloys reaches previously unachievable values ($\leqslant 5\cdot10^{-7}$). Thanks to these properties, amorphous materials are extremely promising for the production of magnetic circuits, transformers and motors (instead of texturized ferrosilicon), the magnetic circuits of magnetic recording heads, magnetic screens and so on.

Thanks to the development of methods for directed action on the external surface of materials in recent years, it is now possible to solve on a qualitatively new level the well known problem of insuring the optimum relationship between the surface's properties and the bulk of the material. Here we are talking about the intensive development work that is being done on methods involving laser treatment, ion doping and modern methods for creating special coatings. The use of these surface treatment methods makes it possible to raise the level of the mechanical and physicochemical properties of material surfaces and achieve fundamentally new effects that are expanding substantially the boundaries of the practical utilization of such materials.

Surface treatment with lasers is being introduced intensively in various technological methods for treating materials. We should also point out the extensive introduction of laser technology in the automobile industry and other branches of machine building, which is being carried out under the leadership of Academician Ye.P. Velikhov. When the treatment modes are varied, it is possible to realize different mechanisms for strengthening material surfaces. For instance, by partially melting the surface of a piece that is being worked, rapid cooling causes the effect of reduction in grain size to be achieved. When working without partial melting, mechanisms typical for traditional hardening methods are realized. As Academician V.D. Sadovskiy points out, phase cold hardening plays the basic role in them.

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[1] See: Masumoto, T., SCIENCE REPORTS JUST TOHOKU UNIV., Vol 26A, No 4/5, 1977, pp 246-262.

Laser chemicothermal treatment, or laser doping, offers extensive prospects for the creation of materials with unique properties. With the help of treatment of this type, by using the effect of rapid melting and hardening it is possible to introduce into the surface layers of steel the most variegated components in combinations and quantities that cannot be achieved by standard chemicothermal treatment methods.

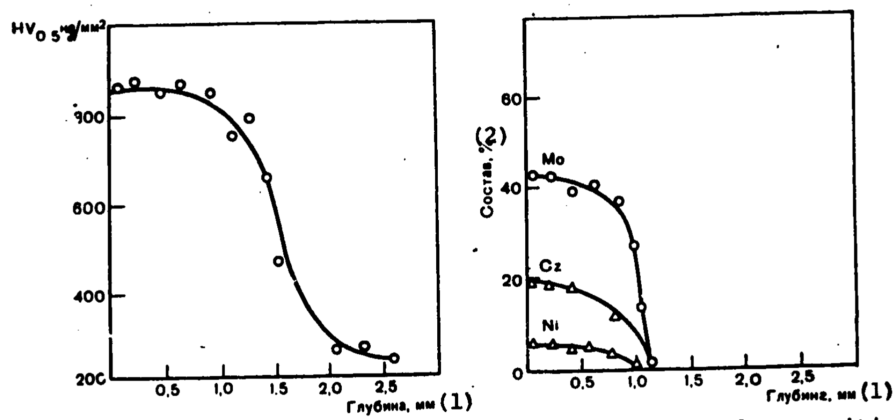

Figure 2. Change with depth of hardness of steel (left) and composition of alloying components (right) after laser chemicothermal treatment.
Key: 1. Depth, mm   2. Composition, %

When the treatment mode parameters (radiated power and duration of the effect on the zone being treated) are chosen appropriately, it is possible to create a given structure in the surface layer of a material. For instance, when fusing together a powder with a complex composition (Mo, Cr, Ni, Si and chromium carbide), using a continuous CO_2 laser with a radiated power of 8-10 kW and an exposure time of about 1 s, in the surface layer of low-carbon steel a structure that insures a fourfold increase in hardness (Figure 2) and has a ramified system of micropores is obtained[1]. Such a structure, as is well known, insures the maximum wear resistance for the parts of a friction assembly that are functioning under hydrodynamic friction conditions.

When creating laser treatment (in the pulsed mode, for example) conditions that insure the hardening rates needed to obtain amorphous alloys from the liquid state, in alloys of the Fe-B-Si type it is possible to create a thin surface layer (about 10-15 μm thick) with an amorphous structure. The nontriviality of this statement is based on the fact that the amorphous phase exists in direct contact with a crystalline phase having the same composition.

At the present time there already exist quite a few publications describing the use of laser thermal and chemicothermal treatment to improve such operating properties as wear and corrosion resistance, thermal stability and so forth. In connection with this, the basic advantages of the laser treatment of materials over furnace and induction heating consist of the possibility of carrying out effective surface thermal treatment with a high productivity rate, including the possibility of local

[1] See: Belmondo, A., and Castagna, M., THIN SOLID FILMS, Vol 64, 1979, pp 249-256.

thermal strengthening of given sections of a surface with minimal distortions of the geometry of the surface being treated and minimal thermal stresses. The latter fact is particularly important when treating precision parts with complex shapes and articles made of cast iron. At the same time, energy consumption for the heating of the inner bulk of a material, which is not being strengthened, is eliminated.

Laser chemicothermal treatment opens the possibility of the widespread replacement of expensive alloyed steels with simple carbon ones. Nevertheless, the present stage of development of this method can be characterized as the initial one, consisting of the accumulation of experimental facts. The quite thorough science of materials analysis of phases and structures that are obtained and the determination of the general rules governing their formation and evolution--in a word, everything that has been developed for traditional thermal treatment methods--is now of no value. This area is still a "blank spot" in science of materials.

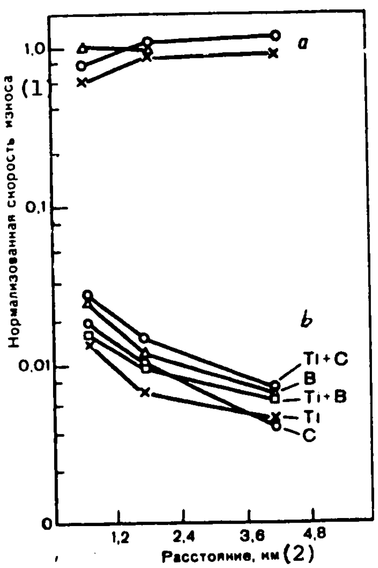

Figure 3. Dependence of rate of normalized wear of stainless steel on slippage distance: a. unimplanted samples; b. implanted samples.
Key: 1. Normalized wear rate
2. Distance, km

This applies to equal degree to methods for treating materials using ion doping. It is now firmly implanted in technological methods for the creation of modern semiconducting instruments, but in the field of metal treatment only the first steps have been taken. The well-known skepticism with respect to implantation metallurgy, which is usually related to the shallowness of the effect on the material (no more than several thousand angstroms) and the relatively complicated and expensive equipment, is disappearing rapidly because of the extensive possibilities of the treatment method. Ion doping makes it possible to introduce, in the required concentration, any admixture in any material at any temperature to a given (within the capabilities of this method) depth. As a result, it is possible to obtain states in the surface layers of a material that are fundamentally impossible to realize by such traditional methods as, for example, cementation and nitriding.

A large part of the different uses of ion doping are related to improving the mechanical properties of the surfaces of metals. This means, primarily, increasing the wear resistance and fatigue strength. For instance, when stainless steel is doped with carbon, boron, nitrogen, titanium or a combination of titanium with one of the named metalloids, the wear resistance of test pieces is increased by a factor of 100 (Figure 3)[1]. In connection with this it turns out to be essential that the effect of the increase in wear resistance penetrates to a depth many times greater than that achievable with an implanted ion.

[1]See: Hirvonen, I.K., et al., THIN SOLID FILMS, Vol 63, 1979, pp 5-10.

This phenomenon is related to radiation-stimulated diffusion, which is well known from the science of irradiated materials and which consists of a significant (up to several orders of magnitude) increase in the diffusion coefficients of a material's components when radiation defects are introduced into it. During ion doping, when the ions' energy can reach 200 keV and the dose is about 10^{18} ions/cm^2, a significant concentration of radiation defects is also achieved. In addition to this, when materials undergoing wear tests are subjected to friction, quite high temperatures are realized at the interacting pair's area of contact, which leads to an increase in the mobility of a material's different components and complexes of them containing radiation defects. Radiation-stimulated diffusion and the local increase in temperature at the point of contact result, therefore, in the propagation in the body of a test piece of a dose of initially introduced ions, the maximum concentration of which is reached at a depth of 500-1,000 Å in the irradiation zone, depending on the nature and energy of the ions.

As far as the detailed mechanism of the process of increasing wear resistance is concerned, because of the insignificant amount of experimental data from investigations of composition and structure, it is still quite difficult to draw even quantitative conclusions. It should be mentioned here that even in materials not doped with ions this multifaceted mechanical process, which is composed of different physicochemical phenomena, has not yet had any clear description at the atomic level. This applies, in equal measure, to the understanding of the phenomenon of an increase in a material's fatigue strength after ion doping.

Ion doping is also extremely promising from the viewpoint of increasing the corrosion resistance of materials. In the first place, it is possible to achieve high corrosion resistance values because of the creation in the surface layer of compounds with new physicochemical characteristics. It is obvious that such is the case when titanium is doped with palladium, when the treated material's resistance to corrosion[1] increases by a factor of more than 1,000. In the second place, when the material to be irradiated and the doping ion are chosen appropriately, along with the energy and intensity of the irradiation, in the treated material's surface layer there appears an amorphous state that is also characterized by increased corrosion resistance (as is the case for amorphous alloys produced by hardening from a liquid state). The possibility of obtaining amorphous states by ion doping methods is also interesting because it can be realized for even pure metals. This has now been achieved in practice for the following systems: copper implanted with tantalum or tungsten and iron implanted with tantalum. The distinctive property of such amorphous states is their high thermal stability. For example, a Cu-W system does not lose the characteristics of an amorphous structure even when it is aged at 600°C for 1.5 h.

As in the case of amorphous layers obtained by laser treatment methods, during the creation of ion-doped layers, the amorphous surface layer coexists with the crystalline state without any disruption in continuity. In both cases the transition from the amorphous to the crystalline state apparently takes place through a series of intermediate states. This type of structure is of extraordinary theoretical interest, since it can give information about the nature and evolution of the amorphous state, which is of importance for the practical utilization of amorphous materials.

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[1] Tomashev, N.D., Guseva, M.I., et al., DOKL. AN SSSR, Vol 256, No 5, 1981, pp 1129-1133.

Yet another significance of practical significance offered by ion doping (mixing) methods is the creation of complex surface compounds that cannot be produced by traditional methods, including methods for hardening from a liquid state and direct ion doping methods. Since the ion doping process is accompanied by atomization of the basic material, for sufficiently large doses a state is reached where no further increase in the concentration of introduced ion in the original material takes place. Depending on the nature of the doping ion and the material of the substrate being doped, as well as the energy and intensity of the ion beam, the maximum ion concentration in the substrate is limited to a certain value. In order to achieve a higher level of concentration of a required ion in a given substrate, the process is conducted in the following manner.

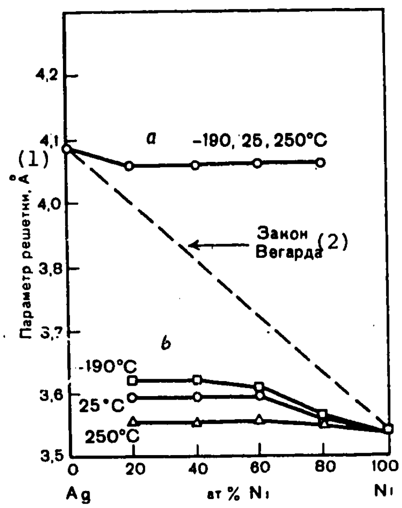

Figure 4. Dependence of lattice parameter of metastable solid alloys formed by ion-beam mixing, at different temperatures, from an initial film composition: a. GTsK [possibly face-centered cubic] solution based on Ag; b. GTsK solution based on Ni.
Key: 1. Lattice parameter, Å
2. (Vegard's) Law

A thin (on the order of several hundred angstroms) layer of the material that is needed in order to obtain the required compound in the surface layer is first applied to the substrate's surface in any manner, such as by thermal evaporation in a vacuum. This two-layered composition is then irradiated by flows of ions of, for example, an inert gas. As a result of the complex processes occurring when the gas ions collide with the atoms of the applied surface layer, as well as the dissipation of the implanting layer's energy, the applied layer mixes with the material of the basic substrate and compounds with different stoichiometric compositions are formed. This method is now the only possible one for obtaining, in a solid state, alloys with a uniform distribution of components in a broad area of concentrations of systems characterized by limited solubility both in the liquid and the solid state. For example, for an Ag-Ni system the maximum equilibrium solubility in the solid state is 0.1 at. % Ni in Ag at 960°C and 2 at. % Ag in Ni near the monotectic temperature of 1,435°C. Over a broad interval of compositions, in the liquid state this system is subject to lamination bec'use of the limited solubility of the components in each other. When the ion-beam mixing method is used on a multilaer composition consisting of alternating layers of Ag and Ni, with the thickness of each layer being 20-100 Å and the total thickness being 800 Å, when xenon ions with an energy level of 300 keV are used it is possible to obtain solid, homogeneous alloys throughout the entire interval of concentrations[1]. An analysis of these alloys showed (Figure 4) that there are two phases present in them: a solution based on Ag and a solution based on Ni, differing not only in the parameters of the crystalline lattice, but also in other properties, in particular the dependence of the Ni-based solution's lattice parameter on the temperature at which the alloy was formed.

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[1]See: Tsanr, B.Y., and Mayer, I.W., APPL. PHYS. LETT., Vol 37(4), 1980, pp 389-392.

The prospects for using ion doping to create materials with special properties are extremely good, and it is already clear that they are far from being exhausted by the examples given above. Therefore, the science of materials aspects of this method of treating material surfaces are becoming the determinant ones for the introduction of ion doping in practice.

The first investigations of the properties of ion-doped layers already show that with this method it is possible to obtain the most variegated structural states and, in particular, stable solid solutions that are typical of equilibrium conditions for solution formation. For example, an Au-Ag system forms a continuous series of solid solutions both for standard methods for the formation of these alloys and when ion doping is used. However, for systems characterized by limited solubility in the solid state, such as Cu-Ag, the solubility limits are enlarged considerably; in other systems there appear different metastable solutions of a substitutional as well as an interstitial nature. The regularities governing the formation of these solutions are not subject to the known rules of alloy formation, although to formulate new rules is still impossible, since only single binary systems have as yet been investigated. The theoretical analysis of this problem is quite complicated, because along with the physicochemical properties of the elements forming the alloys it is necessary to take into consideration the effects caused by the alloy formation process itself, such as the formation of radiation defects, replacement collisions and so forth.

Among the methods for directed action on the surface of solids, the creation of coatings is now the one most commonly used in practice. In connection with this, along with the traditional methods (diffusion, galvanic and so on) intensive development work is being done on new ones: plasmochemical, magnetronic vaporization methods, various methods for ion-beam deposition of coatings and so on.

Progress in the development of these methods is related to the possibility of creating, with their help, coatings from materials from a broad class, ranging from simple materials to complex composition and compounds that determine, in turn, the variegated spectrum of properties of these coatings and make it possible to use these materials in the most widely separated areas of the national economy, from machine building to the production of the very smallest instruments used in medical technology and the submicron elements of semiconducting instruments and superconductors.

Industry--particularly different branches of machine building and the machine tool building industry--is now making extensive use of coatings to increase both the wear resistance and fatigue strength of friction assembly parts, as well as the wear resistance of cutting tools. As a rule, the materials used for coatings of this type are compounds characterized, on the one hand, by a high hardness level and, on the other, low chemical activity. The choice of coating is determined by the fact that in most cases a material's wear resistance is directly proportional to its surface layer's microhardness and inversely proportional to its chemical activity. Allowing for this, as well as economic factors, the coating most commonly used right now is titanium nitride.

For instance, when this coating is produced under certain conditions, it is possible to obtain a microhardness value of about 3,500 kg/mm^2, in connection with which the coating's composition[1] corresponds to a eutectic mixture of 50 percent TiN and 50

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[1] See: Yacobson, B.E., Nimmajadda, R., and Banshah, R.F., THIN SOLID FILMS, Vol 63, 1979, pp 333-339.

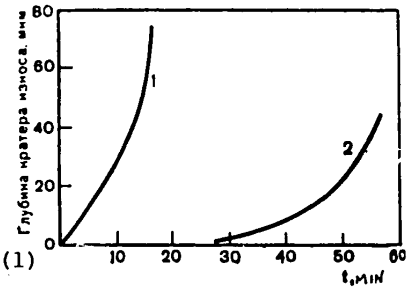

Figure 5. Dependence of depth of wear crater on a cutting tool with different coatings on operating time (cutting rate--160 m/min; depth--2 mm; movement per revolution--0.2 mm): 1. TiC; 2. TiC + Al_2O_3.
Key: 1. Depth of wear crater, μ

percent Ti_2N. One of the essential factors determining the operating properties of coatings is the processes taking place at the coating-substrate interphase boundary, particularly the problem of the coating's adhesion to the substrate. It is obvious that, all other conditions being equal (substrate purity and temperature, the degree of roughness--each of these conditions also has a substantial effect on adhesion), the coating's adhesive properties are determined by the nature of the substrate and coating materials. In order to provide the optimum combination of the requirements for high microhardness and good adhesion, in a number of cases multilayer coatings are created. The use in the tool industry, fc example, of multilayered coatings of the TiC + Al_2O_3 and TiC + NiN types for cutting tools is significant and increases the service life of such an instrument[1] by a factor of 4-10 (Figure 5). In this case the intermediate coating plays the role of a material that "matches" the properties of the substrate and the basic coating. Another variant of changing the conditions of the interphase interaction of the coating and the substrate is the composite method, which combines ion doping with some method for applying the coating. By introducing into the substrate ions of an element or group of elements that are required for good adhesion of the coating that is then applied, it is possible to create a transitional layer of a certain thickness and then apply the coating to it. This procedure is carried out most simply in coating application methods where the deposition takes place from an ion flow.

This is the so-called KIB (condensation with ion bombardment) method. In the initial stage of coating creation, with an ion energy level of up to 10^4 eV, they are introduced into the substrate to a depth of about 40 Å, after which the ion's energy level is lowered and normal coating deposition takes place. The advantages of this method have been confirmed convincingly by measurements of coating microhardness: its level is always higher for composite coatings.

Unique properties are also demonstrated by so-called diamondlike carbon coatings. Descriptions of several different methods for obtaining them have appeared in the literature in recent years. High microhardness and a structure that is close to amorphous are characteristics of all such coatings. When such a film is used to scratch the face of a natural diamond, a clear trail is left on the film, while when the film is scratched with a diamond, intrusion of the diamond into the film is not seen.

Techniques for obtaining the most variegated (from the viewpoint of their future use) coatings have now been developed. They include self-lubricating coatings (of the MoS_2) type, heat- and corrosion-resistant ones, coatings functioning under the

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[1] See: Lindstrom, Y.N., and Johnson, B.F., "Ohlsson FJOW," U.S. Patent No 3837896, 1974.

complex conditions of the combined effect of an aggressive medium and high temperatures and so on. The effectiveness of their use at the present time and further progress in the development of methods for obtaining them depend essentially on our gaining an understanding of the formation and evolution of the coatings' structures and compositions, as well as the processes taking place on the interphase boundaries.

At the present time, the study of coatings in the science of materials is lagging considerably behind their practical utilization. As was pointed out earlier, this applies to all the modern methods for acting on internal and external interfaces and is obviously related to the fact that the layers of a material in which substantial changes take place in both structure and properties as the result of treatment with modern methods are extraordinarily thin. Traditional science of materials methods for investigating such structures cannot produce the necessary information about the processes taking place in these layers.

Therefore, further progress in the development of the science of materials as applied to thin surface layers must be related to the use of modern methods of surface analysis. Quite a few original and summary works devoted to the development and application of modern surface analysis methods have now been published in both the foreign and domestic literature. The spread of these methods to specific science of metals investigations is being held up only because of a lack of the appropriate equipment, since the Soviet tool building industry has only just begun to develop and produce some types of it. The development of the tool building industry for investigations in the field of the science of material surfaces will undoubtedly make it possible to elevate this research to qualitatively a new level.

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